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COMMENTARY AND DISCUSSION ARTICLE

On the uncanny capabilities of consequential LCA

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Abstract
Purpose Plevin et al. (2014) reviewed relevant life cycle assessment (LCA) studies for biofuels and argued that the use of attributional LCA (ALCA) for estimating the benefits of biofuel policy is misleading. While we agree with the authors on many points, we found that some of the arguments by the authors were not presented fairly and that a number of specific points warrant additional comment. The main objective of this commentary is to examine the authors' comparative statements between consequential LCA (CLCA) and ALCA.
Methods We examined the notion that the LCA world is divided into CLCA and ALCA. In addition, we evaluated the authors' notion of "wrong" models.
Results We found that the authors were comparing an idealized, hypothetical CLCA with average (or less than average), real-life ALCAs. Therefore, we found that the comparison alone cannot serve as the basis for endorsing real-life CLCAs for biofuel policy. We also showed that there are many LCA studies that do not belong to either of the two approaches distinguished by the authors. Furthermore, we found that the authors' notion of "wrong" models misses the essence of modeling and reveals the authors' unwarranted confidence in certain modeling approaches.
Conclusions Dividing the LCA world into CLCAs and ALCAs overlooks the studies in between and hampers a constructive dialog about the creative use of modeling frameworks. Unreasonable confidence in certain modeling approaches based on their "conceptual" superiority does not help support "robust decision making" that should ultimately land itself on the ground.

Keywords Consequential LCA · General equilibrium models · Modeling · Taxonomy

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1 Introduction

The Forum article by Plevin et al. (2014) ("the authors" hereafter) provides a review of relevant literature on the use of life cycle assessment (LCA) for biofuel policy. The authors' key message that LCA researchers and practitioners, as well as the audience, should be attentive to the possible consequences of a decision and the conditions under which the results should be interpreted is worth repeating. A simple linear extrapolation of an LCA result, for example, may not provide a sufficient basis for understanding the future environmental implications of biofuel. While we could not agree more with the authors on this very message, we found that some of the arguments by the authors were not presented fairly and that a number of specific points warrant additional comment.

2 Taxonomy

How we classify things often helps us see what we couldn't see before, but it may also make us unable to see what should be otherwise obvious. That is because subscribing to a classification, consciously or subconsciously, leads or misleads our minds toward the frame that is created by the way it is done. Sometimes, the influence a classification has on one's mind can be so powerful that it makes the person completely blind to the things that do not follow the order created by the classification.

Imagine a person who is subscribed, completely without a slightest doubt, to the following taxonomy of animals[1].

> animals are divided into: (a) belonging to the Emperor, (b) embalmed, (c) tame, (d) suckling pigs, (e) sirens, (f) fabulous, (g) stray dogs, (h) included in the present classification, (i) frenzied, (j) innumerable, (k) drawn with a very fine camelhair brush, (1) et cetera, (m) having just broken the water pitcher, (n) that from a long way off look like flies.

For this person, it would be a self-evident fact of life that a "hummingbird" belongs to "fabulous" and a "dung beetle" belongs to "et cetera" in his or her perfectly orderly world of the animal kingdom. Therefore, the fact that there might be a hummingbird belonging to the Emperor or that a dung beetle may look like a fly to some people would mysteriously escape the person's attention. In reality, of course, idiosyncrasies in real-life classifications, if any, are less obvious; so are their mischievous effects to our minds.

In the LCA literature, the field has often been described as a dichotomy between process and input–output approaches. While such a distinction has certainly been useful, describing the LCA field as such did not help the community recognize the hybrid approaches despite their long history of existence (see e.g., Moriguchi et al. 1993).

Plevin et al. (2014) adopt yet another simple and clean dichotomy in LCA:

> there are two different frameworks for performing LCA: attributional and consequential.

This distinction is commonly accepted by the LCA community. Nevertheless, it might be worth examining whether there is anything that we don't see by subscribing to it.

3 Consequential LCA, the almighty

But first, let's, for the time being, suppose that LCA approaches are indeed divided, without any overlap, into two: consequential life cycle assessment (CLCA) and attributional life cycle assessment (ALCA). If so, according to Plevin et al. (2014), CLCA seems to possess almost uncanny capabilities, while ALCA is awfully limited:

> CLCA estimates the effects of a specific action (e.g., a GHG mitigation policy), whereas ALCA does not.;
> CLCA […] can, in principle, serve as a guide to mitigation potential.;
> A conceptually superior approach, consequential LCA (CLCA), avoids many of the limitations of ALCA.;
> CLCA can support robust decision making.;
> ALCA is […] so simple that it fails to answer the policy questions that have motivated its application.

One may notice that the power of CLCA in these sentences is appropriately and cleverly framed using "ideally", "conceptually", "in principle", and "can". But why does one need those framing only for CLCA but not ALCA? To state the obvious, it is because no real-life CLCA can possibly demonstrate all these uncanny capabilities. It is indeed a naïve and mechanistic view—perhaps comparable to that of Laplace[2]—that there is a "know-it-all" model in reality capable of predicting the future consequences of an action. It should not be surprising that even those studies labeled as CLCA by the authors explored, by necessity, only a subset of possible consequences of a decision.

For example, consider a policy that promotes corn ethanol. Such a policy may trigger a diversion of more corn into ethanol, which would increase the price of corn. Farmers on the margin would consider whether to produce more corn by changing their rotation pattern or converting their soy or cotton fields into corn. According to the authors, such decisions can be easily modeled using general equilibrium models (GEMs) or partial equilibrium models (PEMs). But, really? Even within these early stages of the cause-and-effect chains, things are not that straightforward: farmers do not have complete oversight of future price trajectories or future cost prospects to make optimal decisions; and croplands in different locations have different soil and climatic conditions with regard to crop suitability, which are not reflected in the level of spatial granularity presented in those models. Furthermore, there are always many other simultaneous changes in the system such as consumer preference changes, or introduction of new technologies, varieties or agrochemicals, and therefore the fundamental assumption of these GEMs that the economy is in an equilibrium state and that the increase in demand on corn due to biofuel policy is the only trigger that brings it into a new equilibrium is an implausible assumption. Therefore, the use of GEMs or PEMs in real-world LCAs alone does not sufficiently address the complex real-world dynamics to the level that is necessary to justify the authors' characterization of CLCA. These problems are not merely about parametric uncertainties that the authors referred to; it is about the inherent indeterminacy and complexity of socioeconomic dynamics.

[1] This quote appears in the preface of *The Order of Things* by Foucault (1970) which refers to a Jorge Luis Borges' book that again quotes a "certain Chinese encyclopedia". Whether the original literature noted as "certain Chinese encyclopedia" really exists is unknown but it is likely to be a fictitious creation of Borges.

[2] "We may regard the present state of the universe as the effect of the past and the cause of the future. An intellect which at any given moment knew all of the forces that animate nature and the mutual positions of the beings that compose it, if this intellect were vast enough to submit the data to analysis, could condense into a single formula the movement of the greatest bodies of the universe and that of the lightest atom; for such an intellect nothing could be uncertain and the future just like the past would be present before its eyes." [Laplace 1902; *A philosophical essay on probabilities*].

If neither a "know-it-all" model nor a perfect CLCA study that matches the authors' description of CLCA exists in reality, what is the comparison by the authors really about? We argue that those comparative assertions by the authors are about the authors' definition of ideal CLCA versus the authors' definition of typical ALCA. Because ideal CLCAs are defined by the authors to be superior to typical ALCAs, such comparative statements by themselves do not prove or disprove anything about the superiority of real-life CLCAs; they only repeat the authors' definitions of ideal CLCA and typical ALCA.

We are not arguing against the usefulness of entertaining the idea of what ideal CLCAs can or should do. The point is that the ideal CLCA's fantastic performance (or the typical ALCA's awful performance) defined by the authors should not be confused with what CLCA-inspired (or ALCA-inspired), real-life LCA studies actually achieve, and therefore, the characteristics of ideal CLCAs (or those of typical ALCAs) cannot serve as the basis to endorse (or reject) an LCA study only because it is, for some reason, labeled as a CLCA (or an ALCA).[3]

Furthermore, the examples of ALCAs used by the authors to criticize ALCAs are not even typical LCAs: they are generally either poorly performed or poorly interpreted ones. The sense of unfairness while reading the article by the authors seems to arise primarily from the fact that the authors are comparing substandard LCA cases against ideal CLCA, which doesn't even exist in the real-life LCA world, and that the authors use the unfair comparison to support the argument, "CLCA can support robust decision making", while ALCAs, which the authors described as "Most LCA tools and databases […] and published studies", simply can't.

4 Real-life LCAs

A more realistic comparison would be between real-life CLCA and real-life ALCA, if we subscribe to the classification. What makes an LCA a CLCA or an ALCA? Because no real-life LCA can match the descriptions of ideal CLCA, answering this question is not as straightforward as it seems.

One may argue that an LCA study that *aspires* to model the consequences of a decision should be counted as a CLCA. But does mere aspiration really make an LCA study a CLCA? What if the model used in such a study incorporates a few dynamic elements but overlooks the most important ones, and therefore it fails to inform a decision making? Or what if the data used for substitution elasticity, for example, are so outdated that they don't represent the reality?

Or one may argue that an LCA study is classified as a CLCA if it uses a certain class of modeling framework that is associated with CLCA. Indeed, the authors discussed a number of such modeling frameworks including (1) GEMs or PEMs to incorporate substitution elasticity and (2) scenarios. Does it mean that an LCA becomes a CLCA as soon as it uses a GEM, PEM, or a few scenarios, and therefore it becomes more suitable for answering policy questions? Or should it matter whether these tools represent real-life dynamics or how good the underlying data are?

The point is that, as soon as we take a step outside the ideal CLCA world and enter reality, what constitutes a CLCA that makes it worthy of an endorsement for policy applications becomes less obvious.

5 Continuous spectrum instead of a dichotomy

Now, let's, for the time being, reject the notion that the LCA world is divided into CLCA and ALCA. By doing so, one may suddenly see many LCA studies that reside in between.[4] For example, there are obvious ones inhabiting the ecotone: Yang et al. (2012) generally followed the standard LCA framework for their spatially-explicit LCA for biofuels but also incorporated indirect land use scenarios into the model; Suh et al. (2012) developed an interactive, scenario-based LCA tool for biofuel development, which takes into account the dynamics of farmers' choice in response to feedstock and crop prices (Suh et al. 2012). These studies belong neither to the idealized CLCA nor to the typical ALCA the authors defined. In fact, the use of scenarios is very common in standard LCA, and the history of scenarios in LCA goes almost two decades back when the term, "application dependency" was coined by the members of the Society of Environmental Toxicology and Chemistry (SETAC)-Europe LCA working groups (Wenzel 1998; Pesonen et al. 2000; Weidema et al. 2004). Another example is Searchinger et al. (2008), which used a conventional, linear model for most of the study, but also utilized a PEM to calculate the indirect land use change impacts. Interestingly, none of these studies were mentioned by Plevin et al. (2014).

Furthermore, unlike the authors' view, "ALCA does not consider counterfactual uses of inputs, so it cannot account for this," it is a standard procedure to test multiple scenarios for input uses and waste handling options in LCA (Guinee et al. 2002; Weidema et al. 2004; ISO 2006a, 2006b). As discussed earlier, no real-life CLCA achieves the ideal, and, in that sense, all CLCA studies, including those identified by the authors, belong to the space between the ideal CLCA and typical ALCA. Therefore, in reality, the LCA space is more a continuous spectrum, rather than a dichotomy, between idealized CLCA and ALCA.

[3] How one classifies an LCA study as either of the two is yet another interesting problem, which is discussed in the following section.

[4] This was the reason we tried to avoid these terms in our publications.

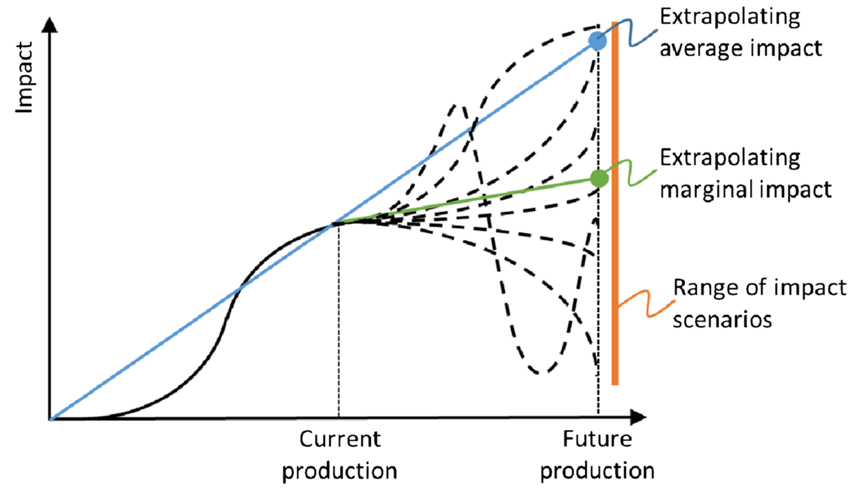

Fig. 1 Illustration of average, marginal, and scenario approaches to model potential future impact

6 Useful models

It doesn't appear to be a coincidence that George E. Box worked on time-series and forecasting (or one may say, "consequential") problems and that he wrote this timeless quote[5]:

> all models are wrong, but some are useful.

In contrast, Plevin et al. (2014) write "Economic theory provides a means of estimating these effects; simply assuming that producing a biofuel suppresses production of an equal quantity of petroleum-based fuel is 'clearly wrong' (York 2012)". Contextually, what the authors refer to as "means" and "these effects" are economic equilibrium models and supply and demand elasticity, respectively. Does it mean that the use of economic equilibrium models makes a model "correct"—or at least less "clearly wrong"?

Equilibrium models, just like any other models, are, however, not free from assumptions, which become at times no less wild than any other models (Rose 1995, Duchin, forthcoming). Equilibrium models may indeed seem "conceptually" superior, as they jointly derive quantities and prices based on supply and demand elasticity. But to do so, one needs to rely on additional assumptions such as perfect information by all economic agents, simultaneous optimization of the entire economy, fixed elasticity functions, etc., as well as incomplete data behind them. Therefore, the use of an economic equilibrium model—or any other models for that matter—in itself does not necessarily make a model "correct".

Plevin et al. (2014) also criticize at length a report by Berndes et al. (2011) despite the fact that the report acknowledged the limitations and assumptions used in the text.

> Presenting a figure with a long list of disclaimers in the text violates the reasonable expectations that a figure means what it says, thus the figure is misleading.

Do the authors think that accounting for supply and demand elasticity or using a few scenarios make the result "correct" or so self-evident that one does not need to explain the assumptions and limitations in the text? We believe that all model results need adequate documentation on the conditions under which they should be interpreted, and the same should apply to CLCAs or GEM results. In this sense, the authors' statement, which was used as a criticism to ALCA, "Properly interpreting any LCA result requires understanding the specific methods, assumptions, and data used in the analysis (Plevin 2009; Farrell et al. 2006), yet the reader encountering a composite figure generally does not have access to the required information." should be equally applicable to GEMs and CLCAs, if not more.

Again, no model is perfect and the question is whether it provides useful insights, which is not a matter of whether it is labeled as a CLCA or an ALCA but a matter of whether it is a plausible or implausible model for the given question and available data.

7 Basic terms and definitions

Before closing, let us discuss a few minor idiosyncrasies in the terms used by Plevin et al. (2014).

> "Whereas ALCA is static, context independent, and average, CLCA ideally is dynamic, context specific, and marginal."

The term "dynamic model" generally refers to a model with a temporal variable. In that sense, GEMs that the authors

[5] In Box and Draper 1987; *Empirical model-building and response surfaces.*

associate with CLCA, in general, are anything but dynamic.[6] It assumes two static, equilibrium conditions, one before and one after an external shock to the system. Equilibrium models generally do not operate as a function of time, and the temporal dimension, if any, is arbitrary.

A simple illustration may help clarify what LCA practitioners generally mean by average, marginal, and scenario approaches. Suppose a simple model that estimates impact (vertical axis) as a function of production (horizontal axis). Estimating the impact of doubling the production volume (future production) may take one of the three typical modeling approaches: (1) extrapolate the average impact (as many biofuel LCA studies have), (2) extrapolate the marginal impact (first order derivative of the function), or (3) use various scenarios or dynamic models to estimate the impacts, among other options (Fig. 1).

Each of these attempts may constitute a possible "what-if" scenario, which may provide useful insights under the assumptions used. For example, the average case can be interpreted as a what-if scenario under which the future impact develops following the historical trend, and the marginal case assumes that the future impact follows the current condition. Depending on the particularities of the system, some of these what-if scenarios may be implausible, but none can be said, by the definition of scenarios, completely "wrong".

8 Closing

Comparing an idealized CLCA with a typical (or less than typical) real-life LCA is neither a fair comparison nor a sufficient ground for endorsing a real-life CLCA. Instead, the discussion should lead to the question, how can a model, or a combination of models, best be used to answer a question recognizing both strengths and weaknesses of different modeling frameworks and available data? Furthermore, the real-life LCA world is more a continuous spectrum of approaches rather than a dichotomy. Dividing LCAs into CLCAs and ALCAs overlooks the studies in between and hampers a constructive dialog about the creative use of modeling frameworks. Finally, unreasonable confidence in certain modeling approaches based on their "conceptual" superiority does not help support "robust decision making" that should ultimately land itself on the ground.[7]

[6] There are "dynamic" GEMs in the literature, but the nature of these models is, strictly speaking, still comparative static.

[7] "A model is essentially a theoretical construct which enables us, starting with some actual or hypothetical data, to arrive at some interesting empirical conclusions. It must start on the ground. It must end on the ground. In between, you can fly as high as you want, but land on the ground again. There are too many models which are still flying." [W. Leontief 1975].

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